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ANALOG COMPUTERS FOR THE EVALUATION OF
AERODYNAMIC COEFFICIENTS

21 APRIL 1964

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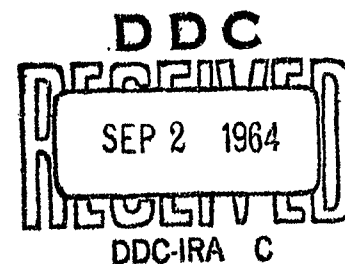
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ANALOG COMPUTERS FOR THE
EVALUATION OF AERODYNAMIC COEFFICIENTS

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ABSTRACT: During static-stability tests in the U. S. Naval
Ordnance Laboratory's wind tunnels, it is desirable to have
the six aerodynamic coefficients computed on-line.   This
report describes the special-purpose analog computers designed
to make these computations and display the results.

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ANALOG COMPUTERS FOR THE EVALUATION OF AERODYNAMIC
COEFFICIENTS

This report has been prepared under Task Number RMMO-42-009/
212-1/F008-09-01 and describes for reference purposes the
aerodynamic coefficient computers employed with the U. S.
Naval Ordnance Laboratory's wind tunnels.

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                                Captain, USN
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                                K. R. Enkenhus

                                K. R. ENKENHUS
                                By direction

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1	Equations for Aerodynamic Coefficients

INTRODUCTION

Results of static-stability tests in the NOL wind tunnels are usually given in the form of the six dimensionless aerodynamic coefficients. Fully corrected evaluation of these coefficients is made by the IBM 7090 computer from raw data recorded on the DARE System (Data Acquisition and Recording Equipment) (see ref. (1)).

During a test it is desirable to be able to monitor results in coefficient form; therefore, it has been the practice to compute these coefficients on-line by means of special-purpose analog computers connected in parallel with DARE. Each coefficient is then displayed as a continuous curve on an X-Y plotter as the model under test is moved through a range of angle of attack or roll angle.

This report describes the present-generation computers in detail and some of the operating procedures which are employed in static-stability tests.

TEST PROCEDURES

During a static-stability test, the various wind forces acting on a model are continuously measured as the model is swept through a range of angle of attack (or roll angle). The "balance" upon which the model is mounted is instrumented with resistance strain gages whose outputs are direct analogs of the forces acting upon them - two gages indicate forces in the pitch plane, two in the yaw plane and one each for roll and drag. It is the output from these six gages, together with positional information, that is recorded digitally by the data system.

COEFFICIENT EQUATIONS

The aerodynamic coefficient equations which are to be evaluated by the analog computer are listed in Table 1. Standard terminology, as prescribed by reference (2), is used. The mathematical derivations of these equations are given in reference (3).

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In these equations the "H" terms are variables representing the outputs from each of the gages and are assumed to be corrected for "zero." The terms A, B, R, S and T represent constants established by the gage factors and physical geometry of the balance, while the qAD terms are functions of model shape and tunnel operating conditions.

The expression for α, the angle of attack, is given in the Table because it is the independent variable against which the six coefficients are plotted.

In the equations for C_ℓ, C_A and α, the last four terms of each are corrections to take care of interaction effects and balance deflection. Interactions among the pitch and yaw gages are compensated for electrically by the data system and thus do not enter these equations. Correction for bending of the balance under air load is normally not necessary in the analog computer but is provided for in case extremely light-load balances are used.

Note that the signs associated with each equation are mathematically correct in accordance with the conventions of reference (2). Electrically, however, this may not be the case. In fact the proper polarity for some terms, such as the interactions, can vary from balance to balance and may not be known. The computer then must incorporate means for reversing polarity of each term as well as of the final coefficient.

COMPUTER DESIGN

The major design requirements for implementing a computer to solve the coefficient equations are satisfied by a circuit such as shown in Figure 1. This represents a third-generation design based upon the general approach detailed in reference (4). The present computers, however, overcome the deficiencies of earlier versions and provide greater capabilities and versatility.

In addition to the circuits required for computing the six coefficients, two channels are included for indicating model position. Active low-pass filters are incorporated in each channel to suppress transients and pickup noise.

A patchpanel arrangement, together with uncommitted switches and pots, permits a wide choice of output connections to the X-Y plotters. The computer components and operating controls are physically arranged to facilitate accurate set up and operation as well as rapid maintenance and trouble shooting.

CIRCUIT DETAILS

Filters

Each transducer signal to the computer is fed through a filter to eliminate any transients or pickup noise. These filters are active second-order low-pass circuits having natural frequencies of either 2 cps or 20 cps, gains of 1 and damping of 0.6. A panel switch is used to select either frequency or to give flat response if desired. Figure 2 shows two configurations of this type filter which give similar transmission characteristics.

For single-input amplifiers the circuit of Figure 2 (b) is employed. As can be seen, this circuit requires more components and gives a phase reversal at its output. A vacuum-tube amplifier is used and resistor R_1 chosen to give sufficiently high input impedance at dc. The feedback resistor, Ro, is made equal to R_1 so that an overall gain of 1 results.

For both filter configurations, one pair of capacitors is used and frequency selection is made by switching different values of resistors. A damping factor of 0.6 was chosen to give a sharp corner at the cutoff frequency with good response uniformity within the passband.

C_N and C_Y Circuits

Figure 3 shows a somewhat simplified circuit for computing normal-force coefficients – the circuit for side force is identical. By letting the two segments of the pot represent $1/A_N$ and $1/B_N$, respectively, and the feedback resistor represent $1/qA$, it can be seen that the output of the summing

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amplifier will be a direct representation of C_N; i.e.,

$$C_N = \frac{1}{qA} \left[\frac{-H_1}{1/A_N} + \frac{H_2}{1/B_N} \right]$$

$$= \frac{1}{qA} \left[-A_N H_1 + B_N H_2 \right]$$

The negative sign for the output of the forward pitch gage (H_1) is obtained by use of an inverter, while the output of the aft pitch gage (H_2) is supplied directly. In the event the two gages are not wired to give the same electrical polarity, a switch allows the inverter to be bypassed. An additional inverter at the output is provided to establish proper polarity of C_N for plotting and for use in setting interaction constants. The output pot provides for a scaling factor to match the grid lines on the plotter paper.

The constants A_N and B_N are determined by the sensitivity of the two pitch gages and the spacing between their electrical centers. Since similar gages are used at the two locations, the constants will normally be almost equal and the pot will be very close to center. This is an aid in setting up the computer for use before a test. In the actual circuit padding resistors are used at each end of the pot. These serve the dual purpose of providing greater resolution in setting the $A_N - B_N$ control and of limiting the maximum gain of the summing amplifier.

C_m and C_n Circuits

The equations for pitching and yawing moments are similar in form to the force equations and could, within limits, be solved by the same type of circuit. A severe restriction arises, however, from the nature of the constants A_m and B_m or A_n and B_n. In addition to gage sensitivity and spacing, these constants are functions of the spacing between each gage and the point about which the moment is to be computed (c.g.). Thus, if the c.g. is located directly over the aft

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pitch gage (H_2) the constant A_m becomes zero (and B_m = "1").
It can be readily appreciated that the circuit of Figure 3
will not permit setting a factor of "0" without driving the
amplifier into overload.

To permit unlimited choice of c.g. location, then, the
circuit of Figure 4 was developed. Here the constants are
determined by taking proportions of the input signals H_1 and
H_2 rather than by series resistors. By ganging the two pots
it is seen that as one constant approaches "0" the other
approaches "1." Note that it is the ratio of the two constants
that is of more significance than the absolute value of
either.

Polarity reversing and scaling controls are employed
similar to those in the force circuits. The factor "d" which
appears in the moment equations is a constant determined by
model dimensions and is implicit in the scaling established
by the output pot.

C_ℓ and C_A Circuits

Two circuits for computing the rolling-moment coefficient
are shown in Figure 5 - similar configurations are used to
compute the axial-force coefficient. In circuit 5(a) the
1/qA control is actually a form of Kelvin-Varley circuit
modified to work into the lower impedances encountered with
transistor amplifiers. It has the advantage of requiring one
less amplifier than circuit 5(b).

In both circuits shown the interaction terms of the
equations, TC (or SC), are summed in the proper mathematical
polarity. These factors are obtained from pots across the
outputs of the force and moment circuits as shown in Figure 1.
The scaled values and electrical polarities are established
experimentally for each balance when the computer is set up.

α and ϕ Circuits

The indicated angle of attack, α_i, is obtained from a servo
driven pot as the model is swept over a prescribed range. In
the computer this signal is fed through a filter, driver

amplifier and scaling pot, as shown in Figure 1, and then patched to the X-axis of all plotters in parallel.

As shown in Table 1 the indicated angle of attack can be corrected for bending effects by summing in factors proportional to the pitch coefficients. In addition, if the balance is to be rotated also factors proportional to the yaw coefficients are included. For most balances this bending is small enough to be ignored in the plotted results. The corrections are available in the computer, however, if needed.

The roll angle, $\emptyset$, is also fed through the computer but needs no correction factors. Having both positional signals available from independent channels permits different plotter scales to be set up and rapid switching when a test program includes both α and $\emptyset$ cuts.

qA Controls

From Table 1 it can be seen that the term 1/qA is a common factor in all six coefficient equations. The "A" is the cross-section area of the model, while "q" represents a pressure term that is dependent only upon the Mach number for an atmospheric supply tunnel. Once the computer is initially set up for a particular test it is necessary only to change the "1/qA" factor when Mach number is changed.

In both computers the 1/qA factor for all six coefficients is simultaneously set by means of ganged controls. These are arranged to give three decades of adjustment. Where 1/qA is determined by feedback the circuit takes the form of a simple variable resistance – where it is achieved by potentiometer a modified Kelvin-Varley circuit is used to give the necessary three decades.

It should be noted that 1/qA is an arbitrarily scaled quantity in the actual computer set up. The major requirement for such a control is to permit rapid change of scale when more than one Mach number is to be used in a test.

PROGRAM PATCHPANEL

Although the computers are special purpose units, they incorporate a degree of operational flexibility through use of

program patchpanels. The patchpanel wiring allows free choice of input and output connections and optional utilization of uncommitted pots and switches. This allows switching between different plotter scales, plotting one coefficient against another, independent use of the filter amplifiers, etc.

COMPUTER USE

The two coefficient computers currently in use at the NOL wind tunnels are shown in Figures 6 and 7. The computer associated with Hypersonic Tunnel No. 8, Figure 6, has been completely rebuilt around the vacuum-tube amplifiers of an earlier model. These amplifiers have only single inputs and the circuits were developed accordingly, as described earlier. The computer shown in Figure 7, which serves Supersonic Tunnels Numbers 1 and 2, was designed around transistorized-operational amplifiers, having differential inputs. Both computers normally operate on single-ended signals supplied from the input amplifiers of the main data systems. The outputs normally drive Moseley X-Y plotters.

Detailed instructions for setting up a computer for static-stability tests are beyond the scope of this report. In general, this procedure involves the experimental adjustment of machine constants and scale factors to establish outputs in agreement with previously calculated values. Signals from each of the strain-gage transducers are generated by applying known forces and moments to the balance by means of weights. Scaling is established on the X-Y plots in accordance with the expected variation of the coefficient and the range of model movement. During the actual tunnel blow operation , the computer is fully automatic, the plotters are continuously supplied, the computer outputs and the pens are lowered for plotting by command of the main data systems.

The method of establishing the computer constants from known forces and moments results in extremely accurate computation, and the use of high-quality amplifiers and components insures that the initial adjustments are maintained throughout a test program. The on-line computation capability provided by these computers has proved extremely useful during static-stability tests in the NOL wind tunnels.

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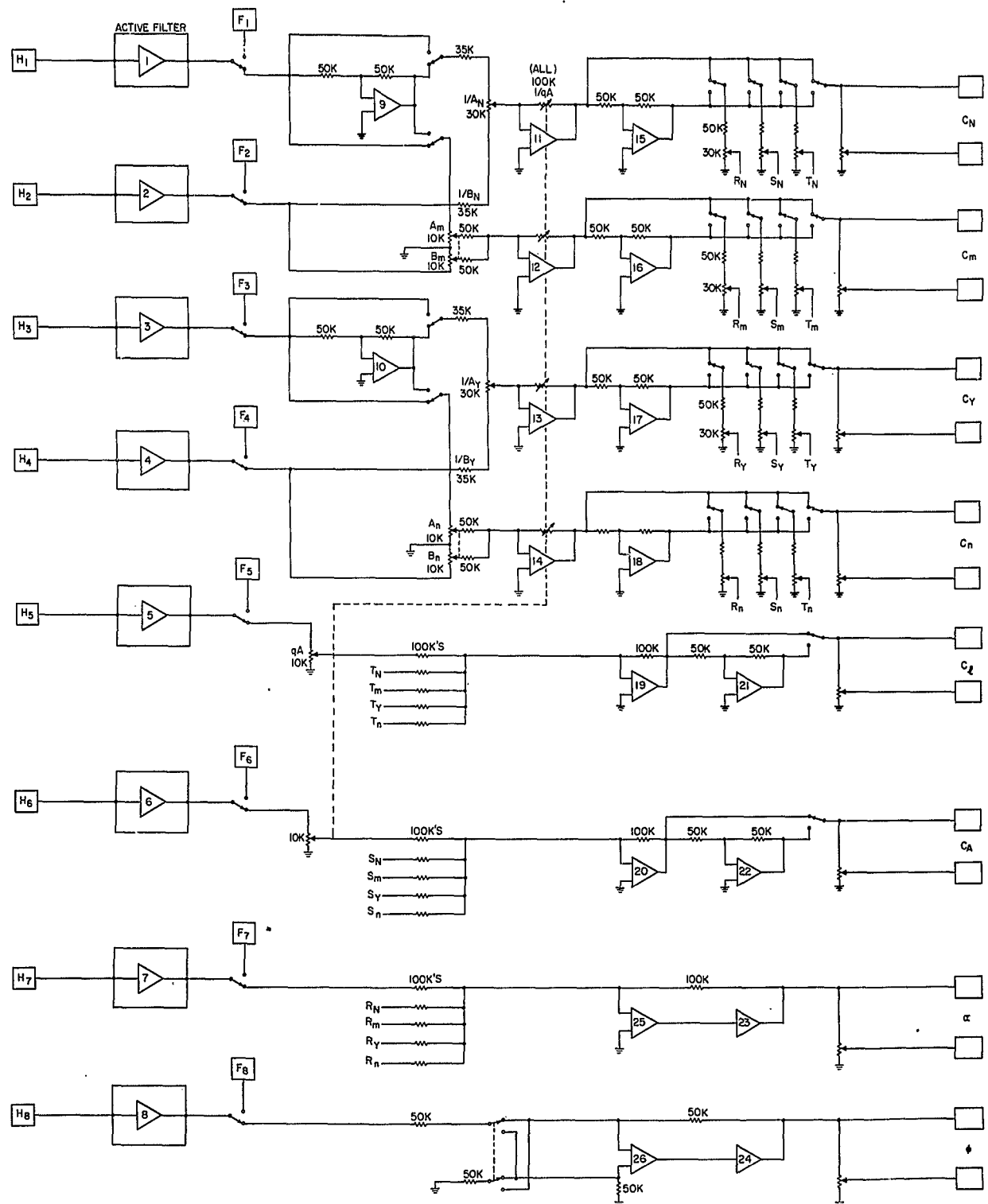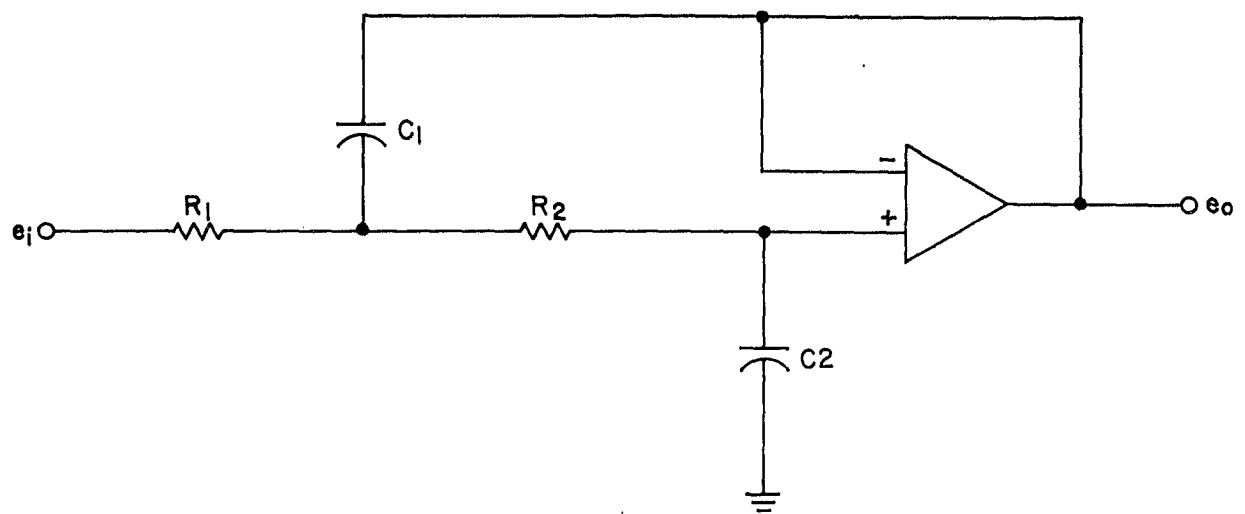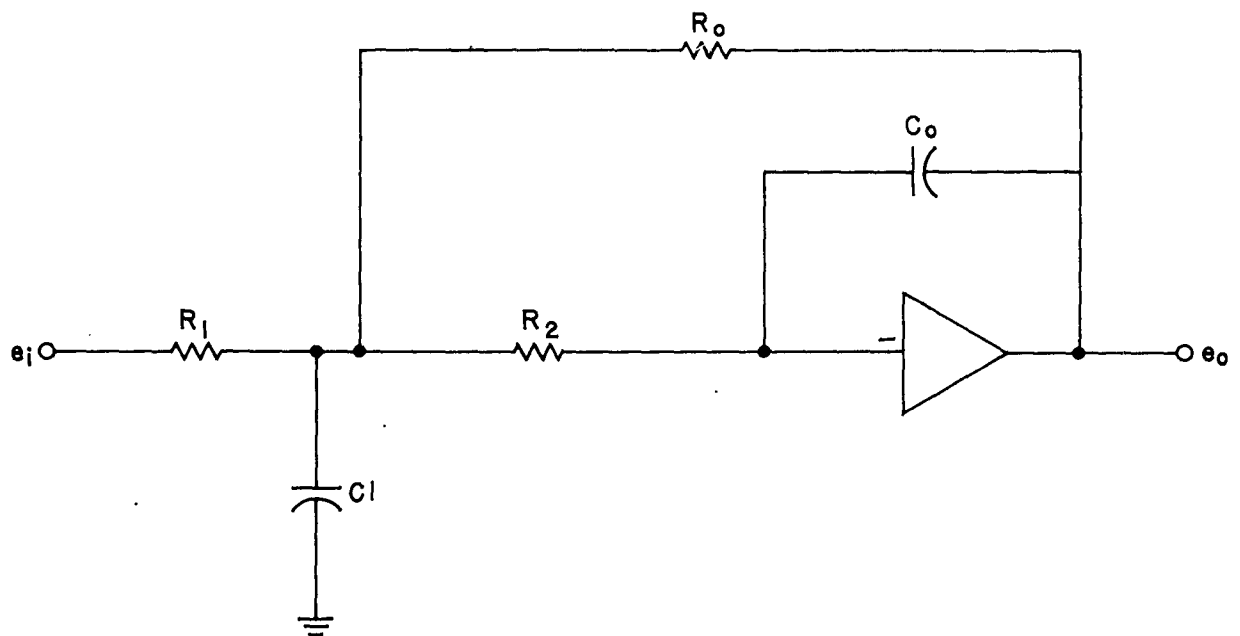   Oct 1957 Unclass

FIG. I COEFFICIENT COMPUTER BASIC CIRCUIT

(a) FOR DIFFERENTIAL AMPLIFIER

(b) FOR SINGLE-ENDED AMPLIFIER

FIG. 2 LOW-PASS ACTIVE FILTERS
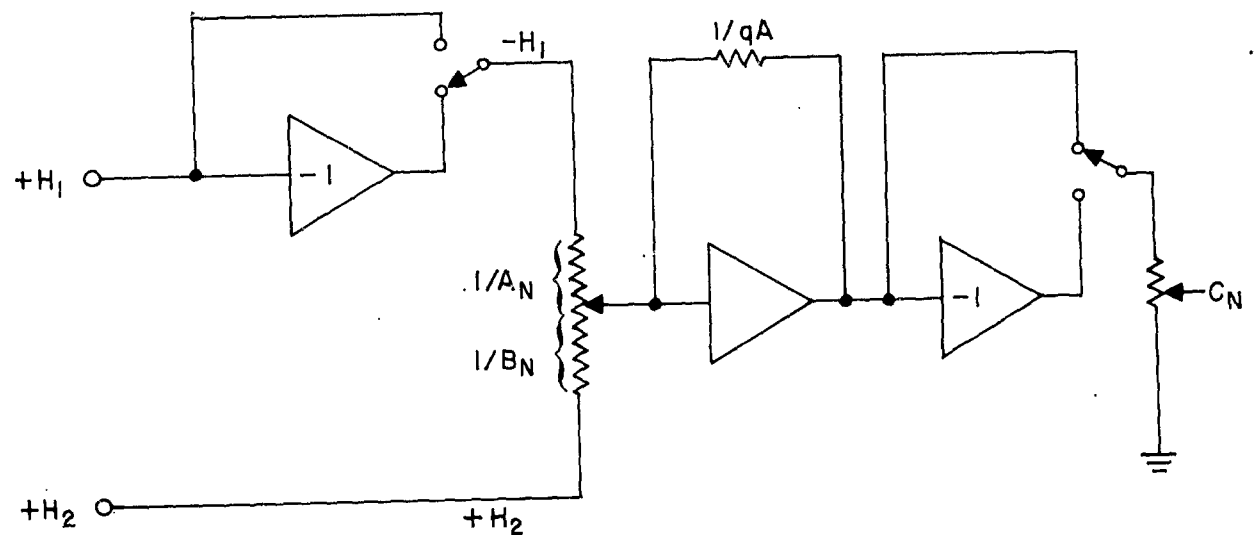
FIG. 3   NORMAL FORCE CIRCUIT (SIMPLIFIED)
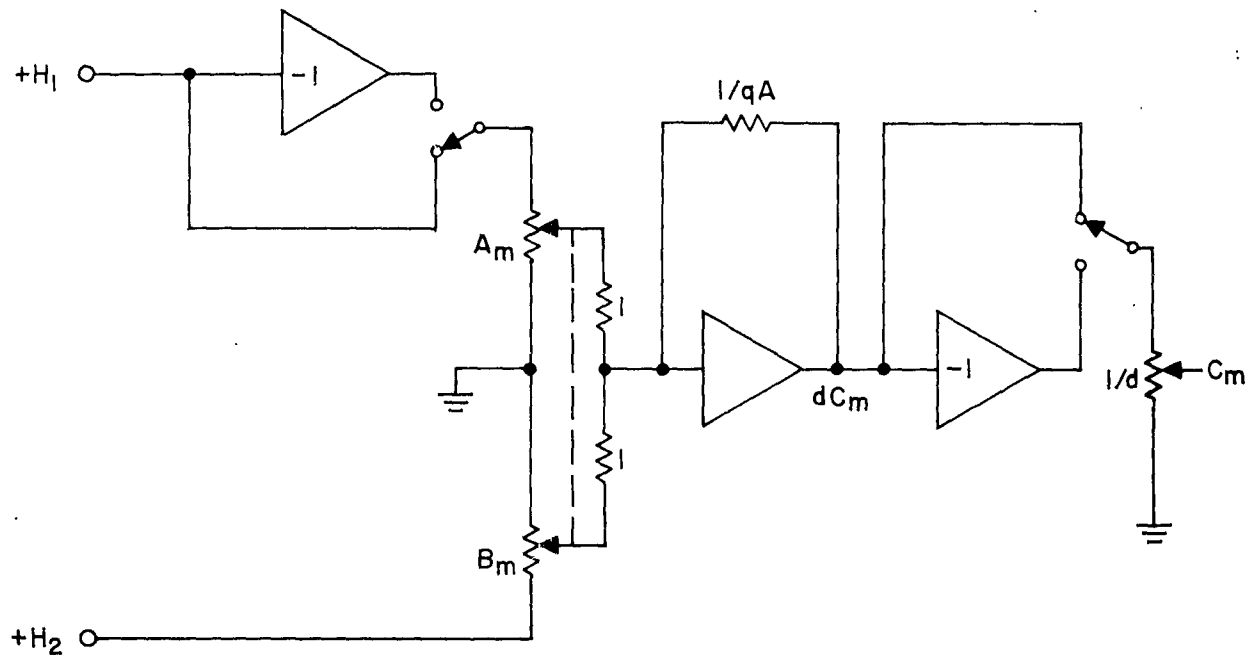
FIG. 4   PITCHING MOMENT CIRCUIT (SIMPLIFIED)
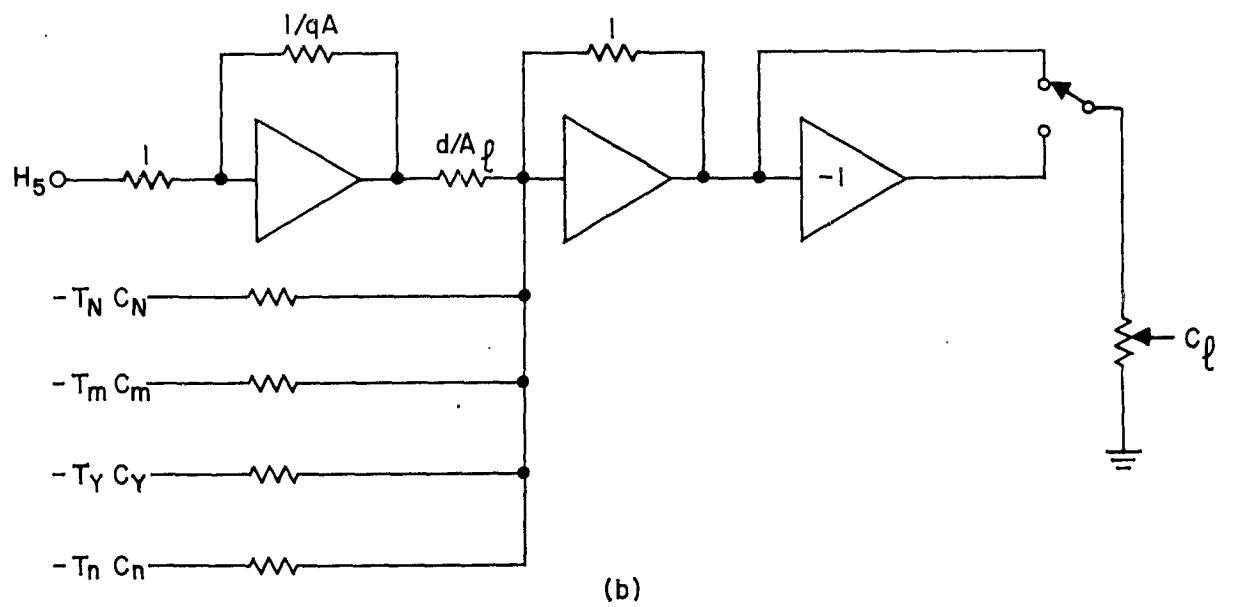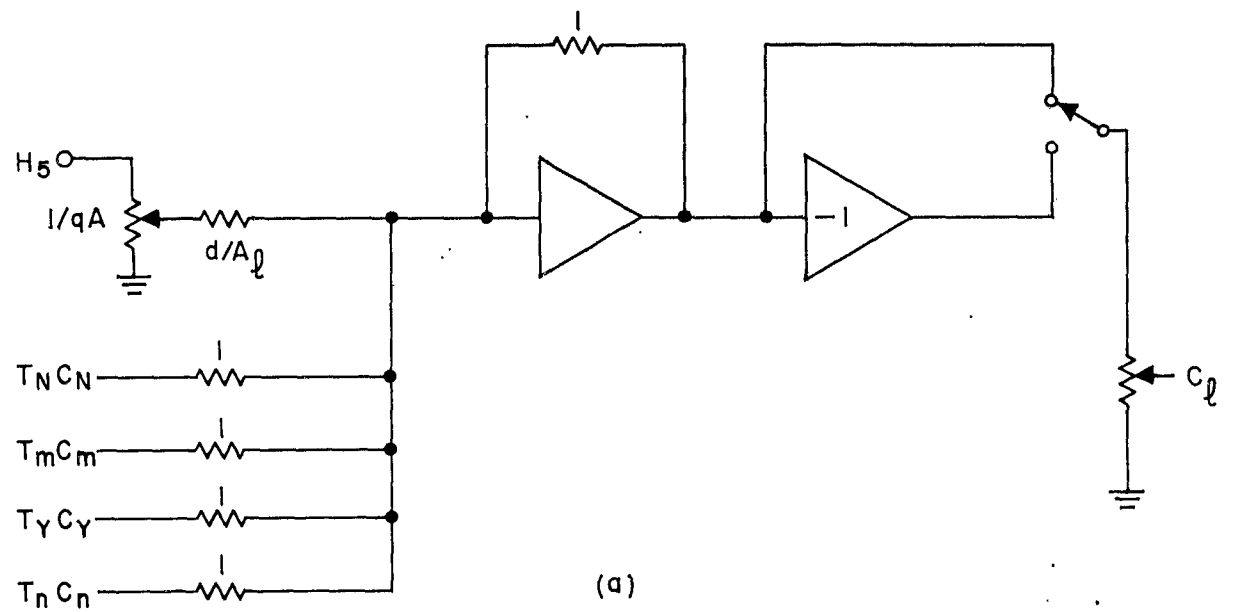
FIG. 5   ROLLING MOMENT CIRCUITS
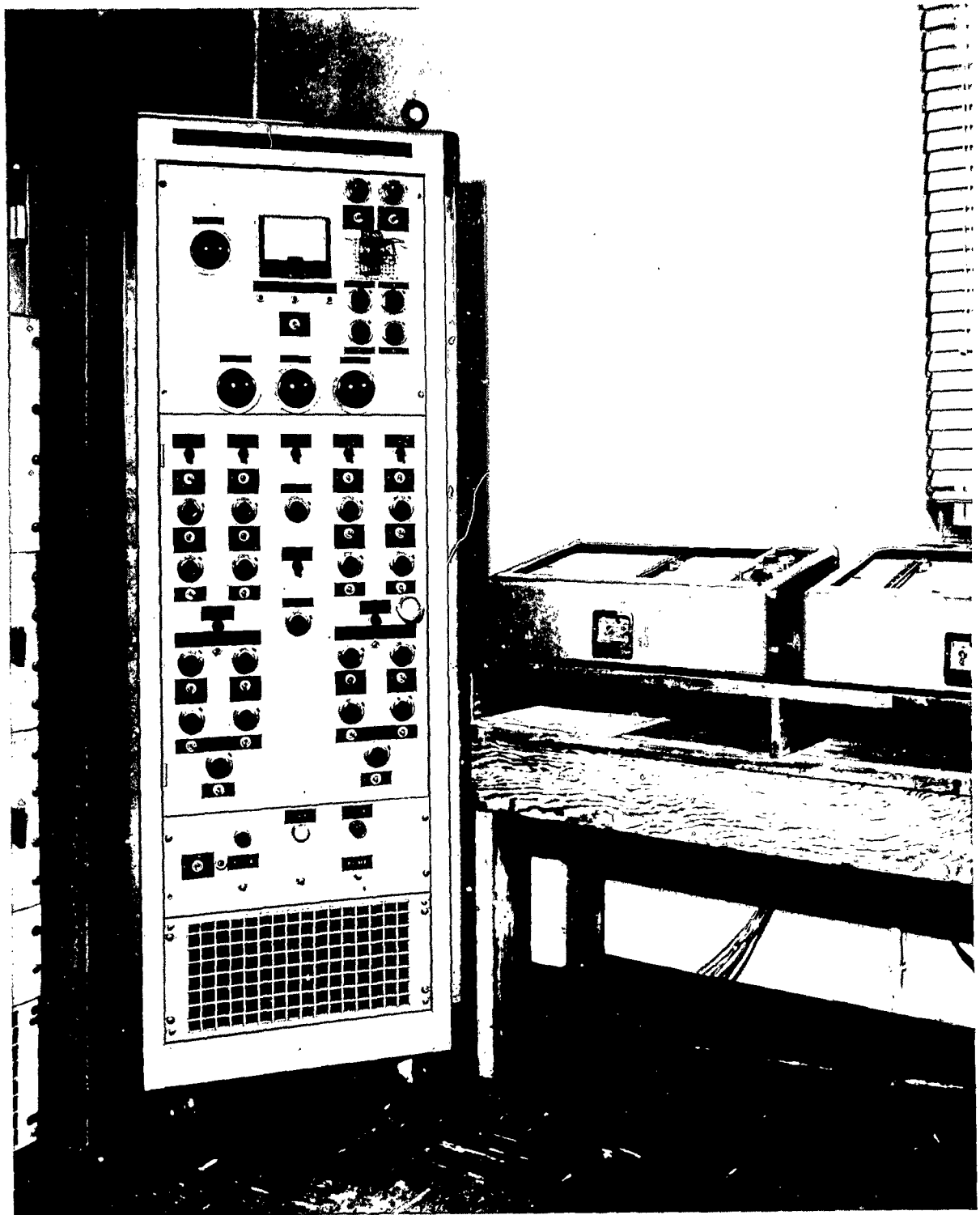
FIG. 6   ANALOG COMPUTER, H. T. NO. 8
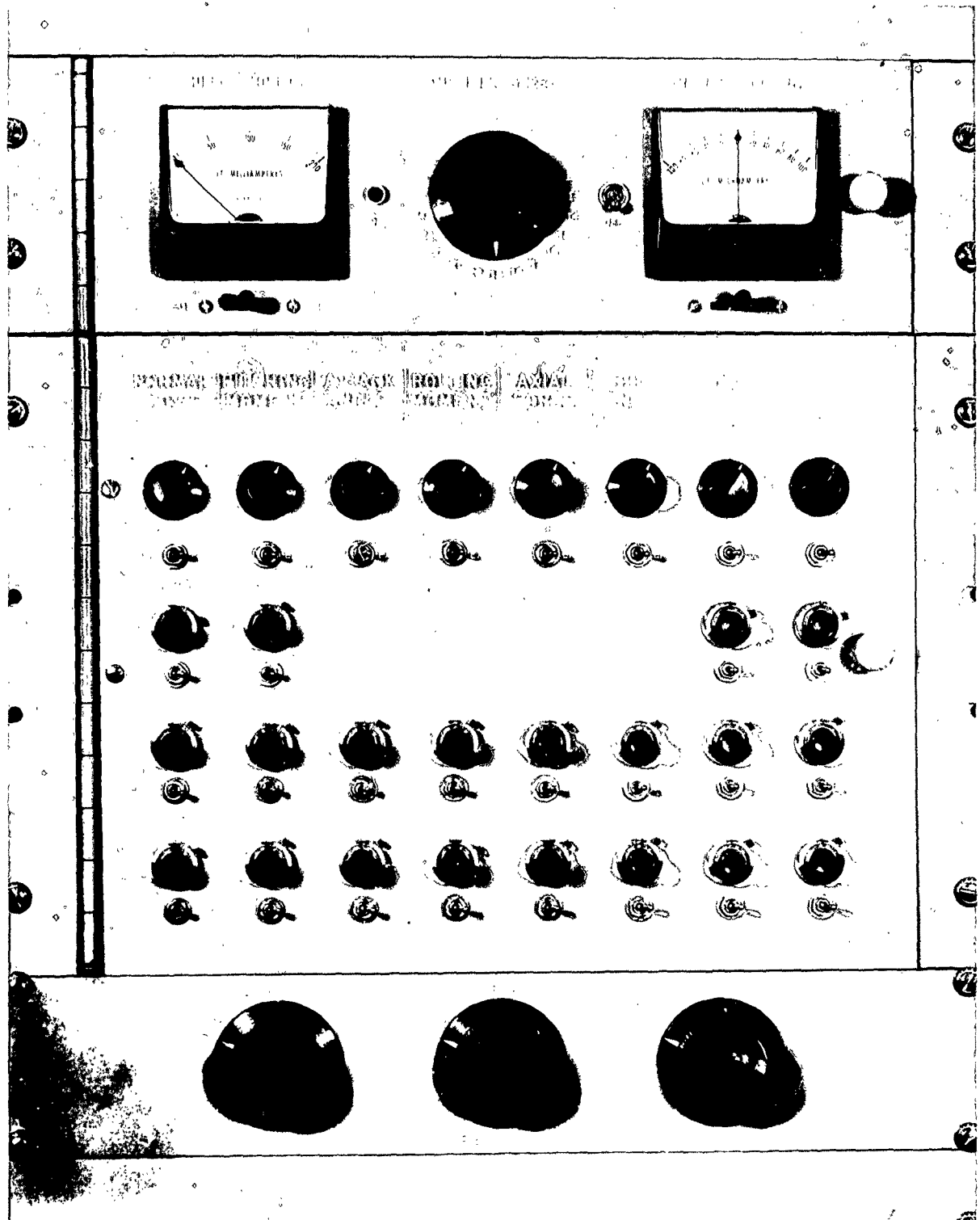
FIG. 7   ANALOG COMPUTER, S.T. NO. I

TABLE 1

EQUATIONS FOR AERODYNAMIC COEFFICIENTS

NORMAL FORCE:

$$C_N = \frac{1}{qA} \left[-A_N H_1 + B_N H_2 \right]$$

PITCHING MOMENT:

$$C_m = \frac{1}{qAd} \left[+A_m H_1 + B_m H_2 \right]$$

SIDE FORCE:

$$C_Y = \frac{1}{qA} \left[-A_Y H_3 + B_Y H_4 \right]$$

YAWING MOMENT:

$$C_n = \frac{1}{qAd} \left[+A_n H_3 + B_n H_4 \right]$$

ROLLING MOMENT:

$$C_\ell = \frac{1}{qAd} \left[+A_\ell H_5 \right] -T_N C_N - T_m C_m - T_Y C_Y - T_n C_n$$

AXIAL FORCE:

$$C_A = \frac{1}{qA} \left[+A_A H_6 \right] -S_N C_N - S_m C_m - S_Y C_Y - S_n C_n$$

ANGLE OF ATTACK:

$$\alpha = \alpha_i + R_N C_N + R_m C_m + R_Y C_Y + R_n C_n$$

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